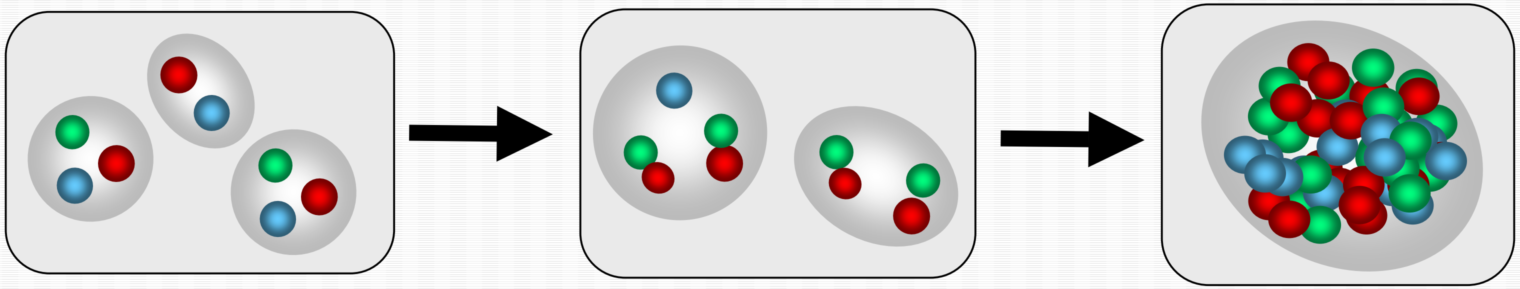
Structure and Production of Exotic Baryons

Atsushi Hosaka (RCNP, Osaka Univ)
Aug. 2 (2004), NP04@Tokai



Contents

From ordinary hadrons to exotics (multiquarks)
Role of chiral dynamics (and confinement)

- Baryon spectra

  Good systematics, with some exceptions

  Interesting physics
- $\Lambda(1405)$ with some emphasis on
- $\Theta(1540)$ **chiral symmetry** of QCD

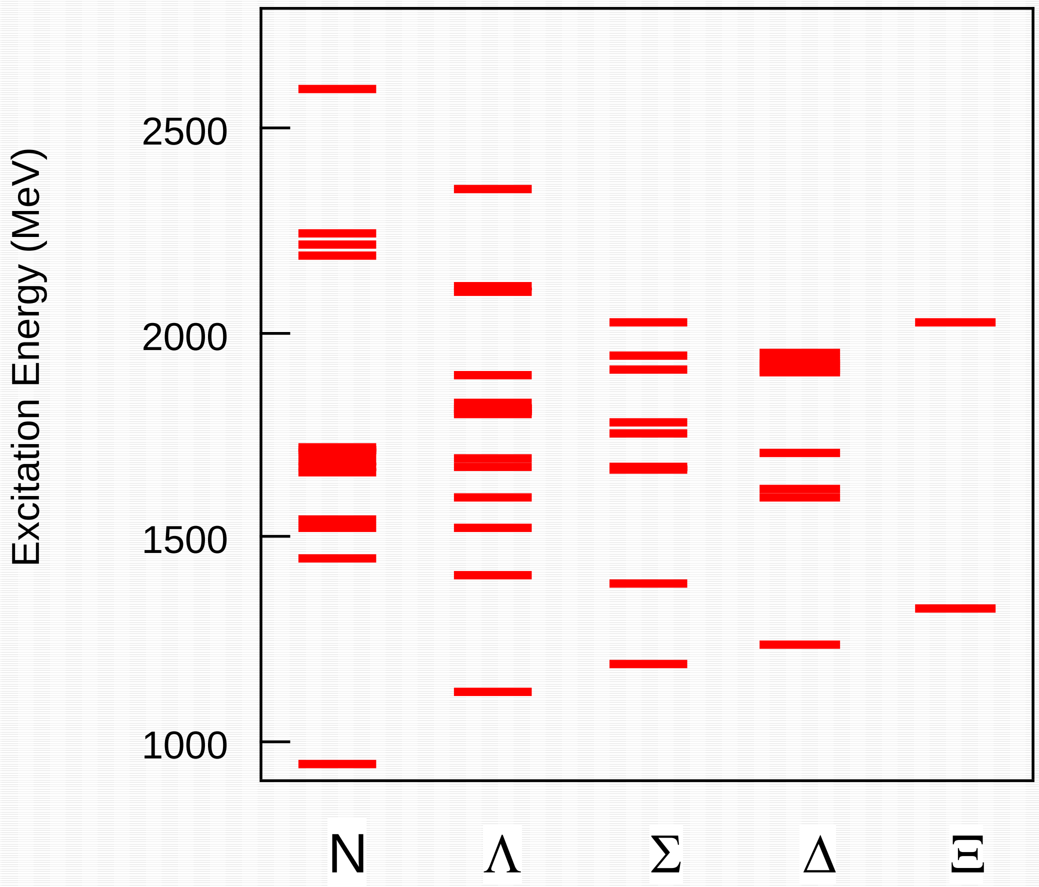
Baryon spectra

Takayama-Toki-Hosaka
Prog.Theor.Phys.101:1271-1283,1999

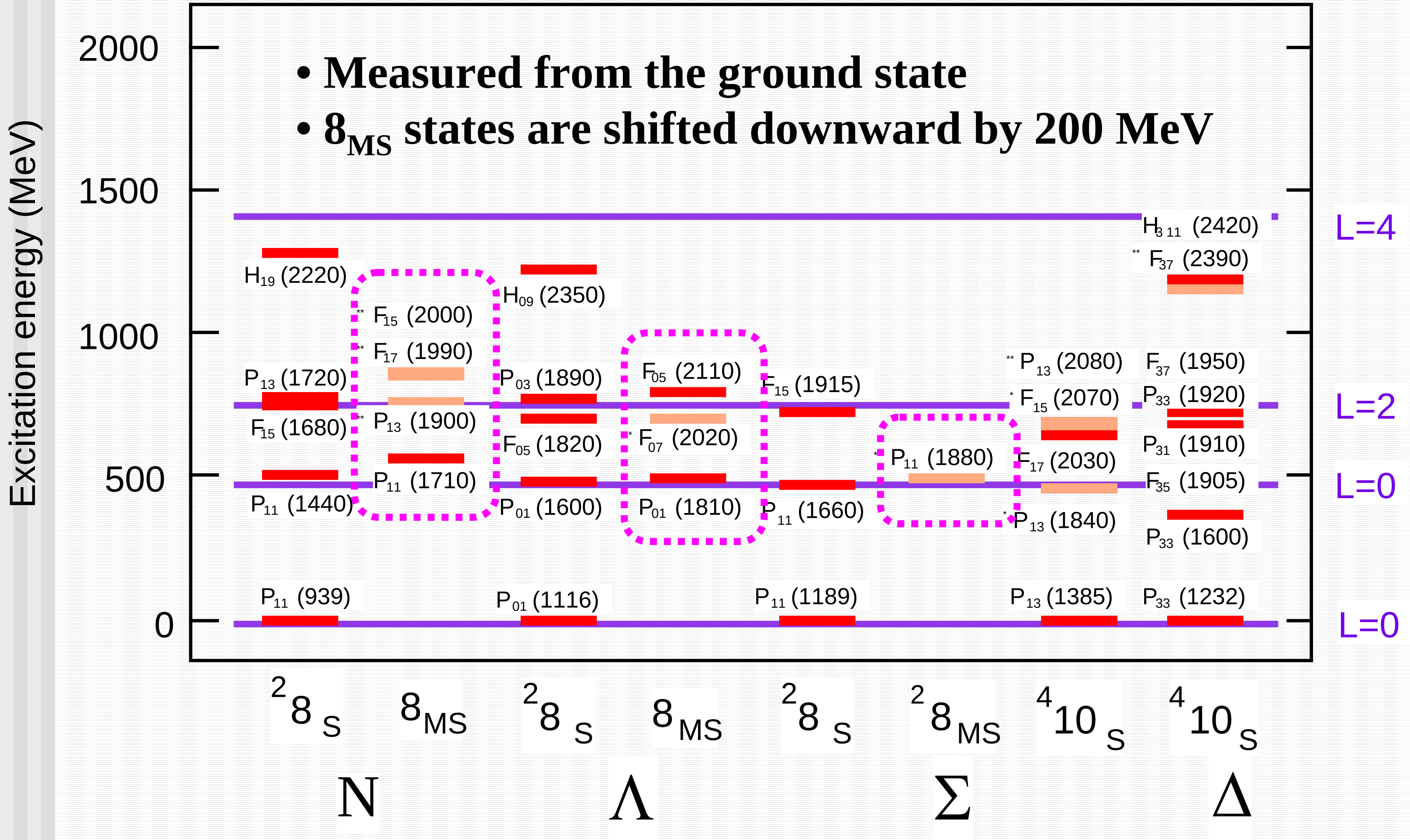
Well established states in uds baryons

49 ***,**** states out of 50
13 * , ** states out of 31

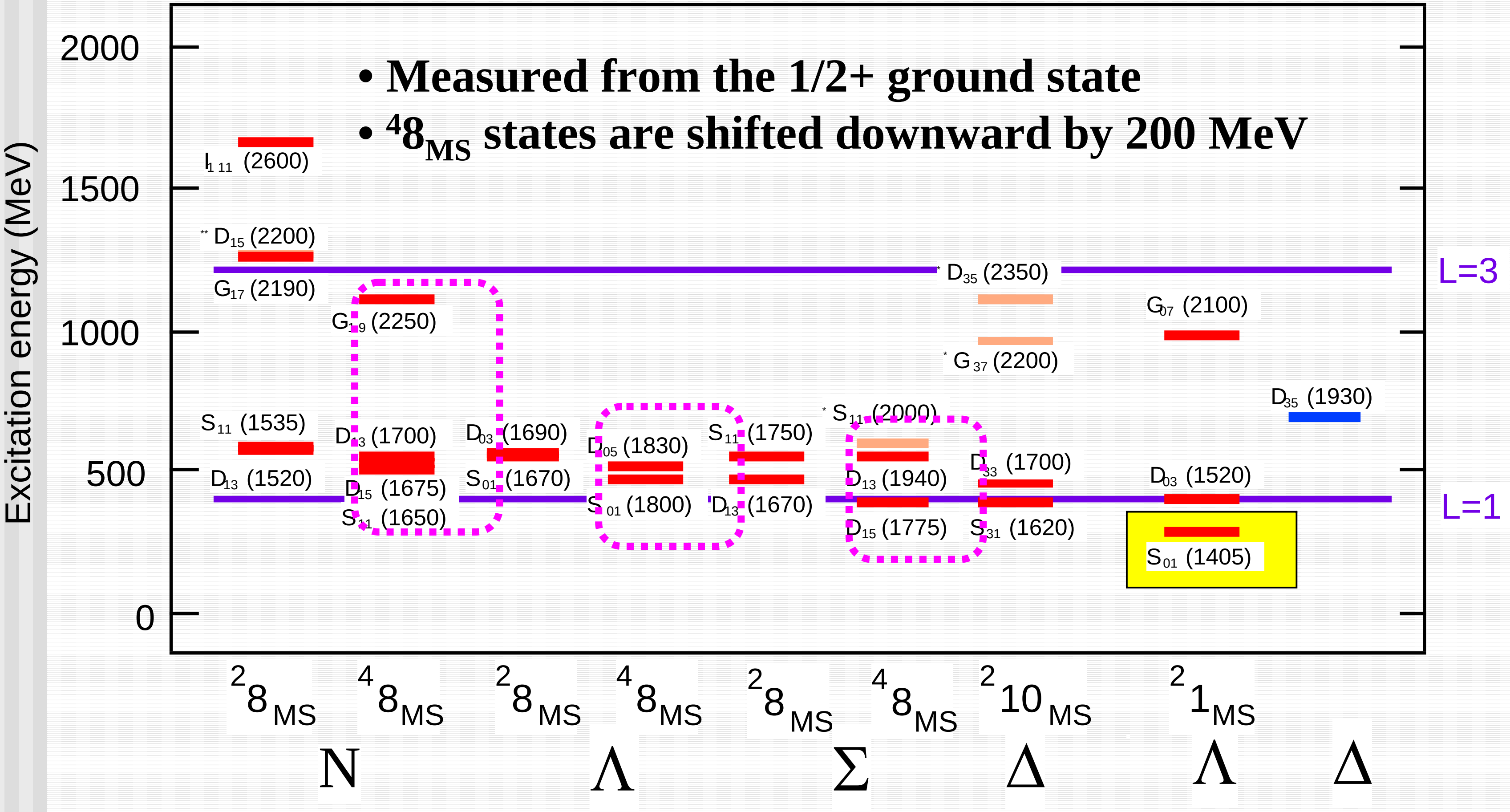
62 states out of 81 states



Positive parity



Negative parity

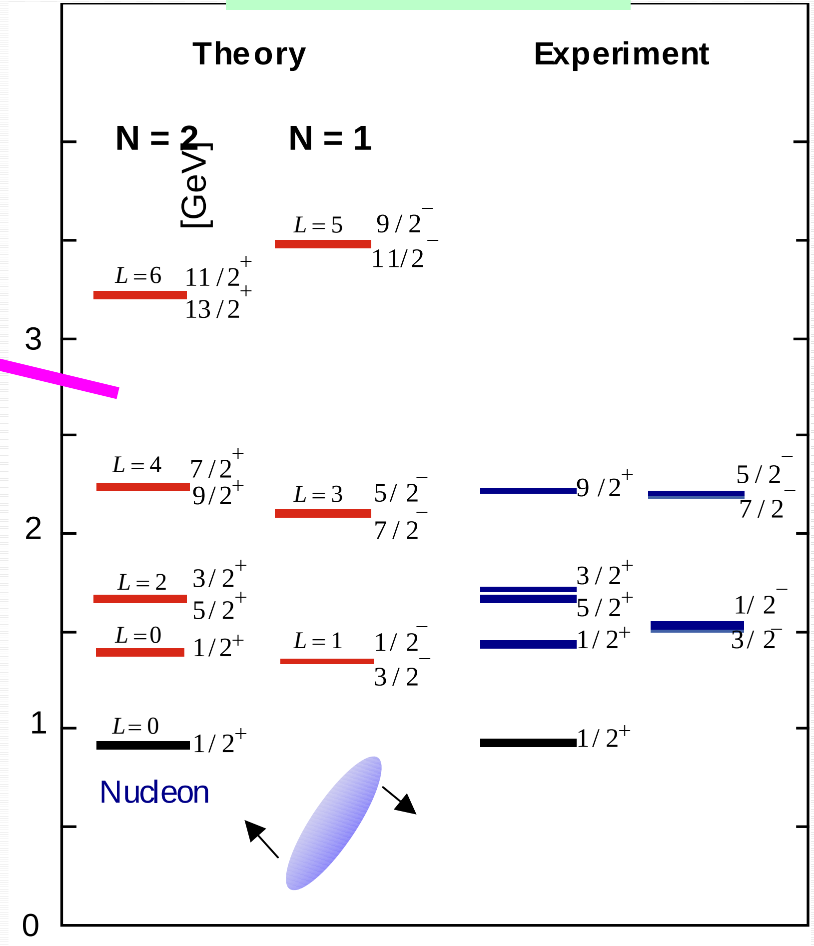


Observations

- Rotational band
  Roper is the band head ?

- $1/2^-$ Levels scatter
  Strong meson-baryon correlation
  due to chiral symmetry
  =>
  Renormalization due to meson cloud
  is important ~ **Λ(1405)**

Nucleon spectra



Quick summary

- There is nice **systematics** in baryon spectrum
  Some are out of it

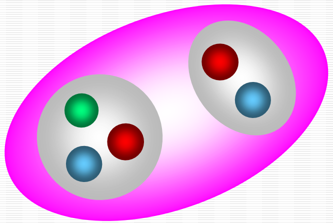
- **Λ(1405) KN quasi-bound state?** **S=-1**

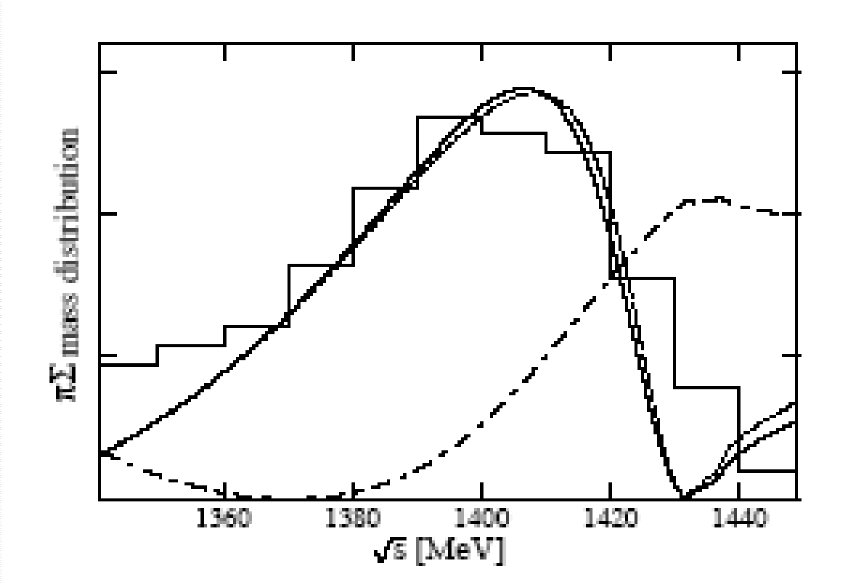
  N(1535) Mirror chiral partner of N(939)
  Jido-Oka-Hosaka, Prog.Theor.Phys.106:873-908,2001

- **Θ(1540) Pentaquark** **S=+1**

Does **chiral symmetry** play an important role?
Strangeness

Λ(1405)

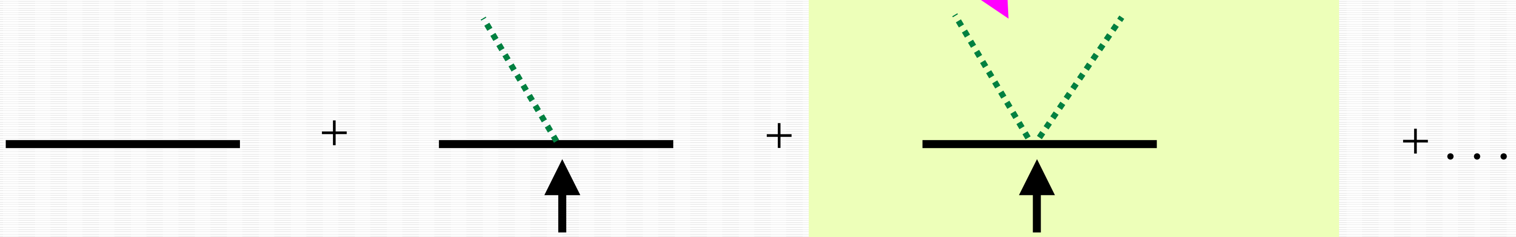




Chiral lagrangian

- **Chiral unitary model (2001~)**
  - J. A. Oller, *et al.* PLB500, 263
  - E. Oset, *et al.* PLB527, 99
  - D. Jido, *et al.* PRC66, 025203
  - T. Hyodo, *et al.* PRC68, 018201
  - C. Garcia-Recio, *et al.*, PRD67, 076009
  - D. Jido, *et al.*, NPA725, 181
  - T. Hyodo, *et al.* PRC68, 065203

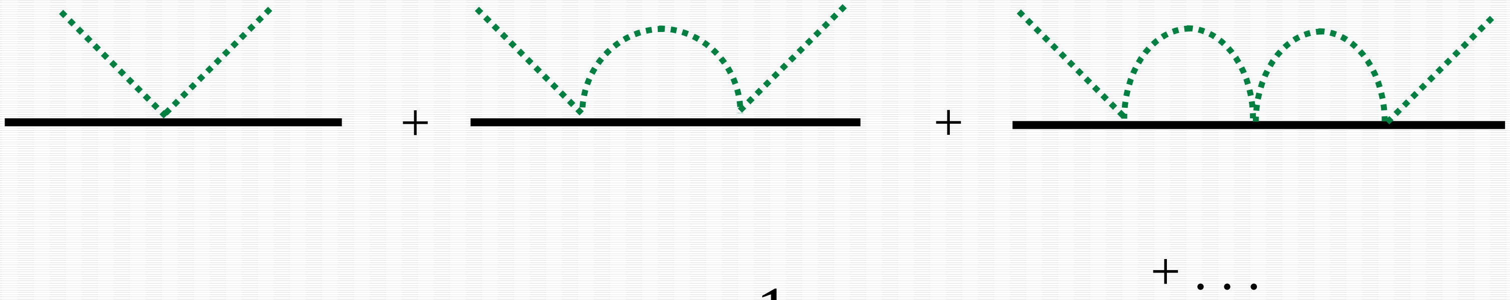
$$\mathcal{L}_{WT} = \frac{1}{4f^2}\mathrm{Tr}(\bar{B}i\gamma^{\mu}[(\Phi\partial_{\mu}\Phi - \partial_{\mu}\Phi\Phi), B])$$



Yukawa
~ Axial current

Tomozawa-Weinberg
~ Vector current

Meson-baryon scattering



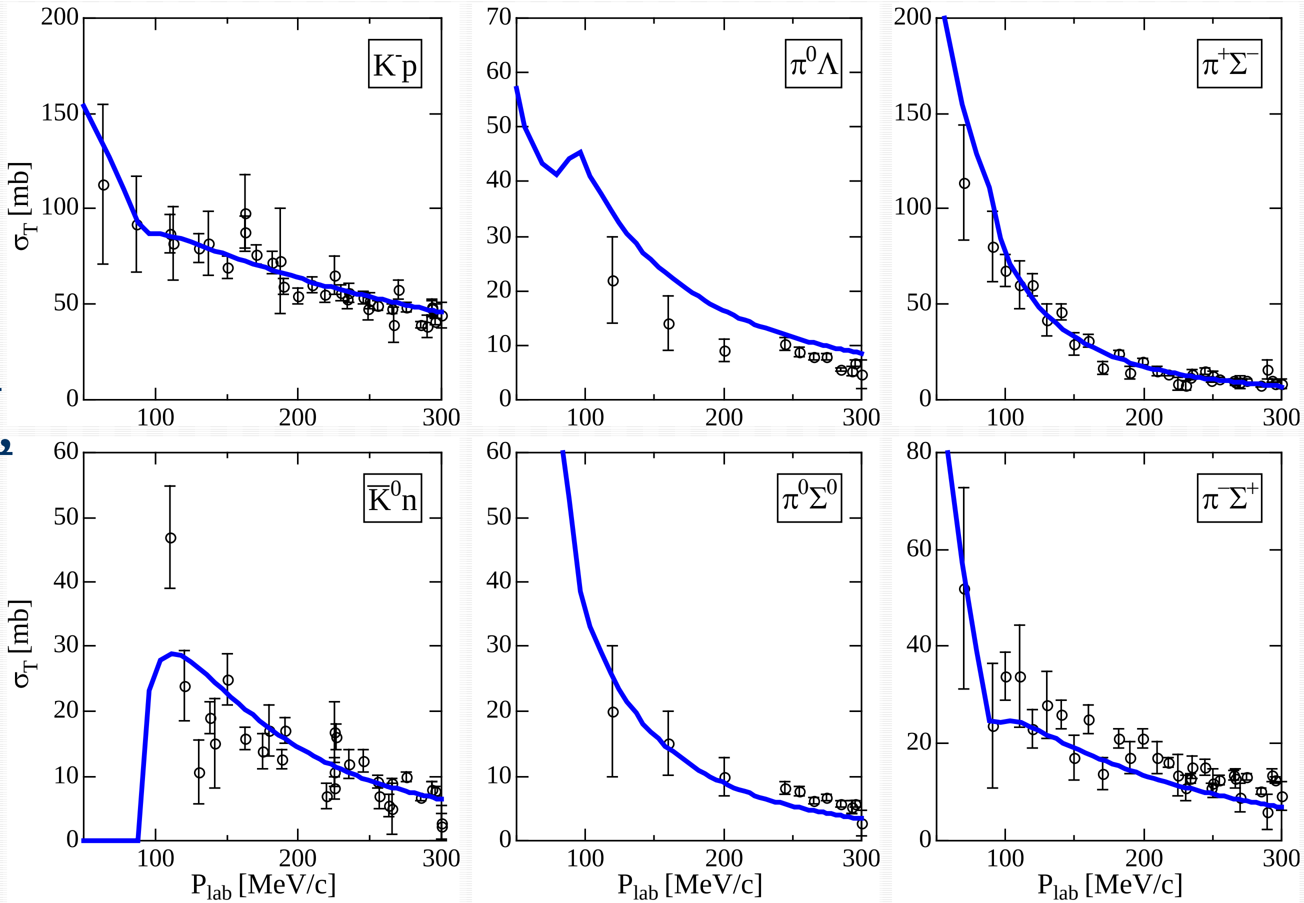
$$T = V + V \frac{1}{E - H_0} T$$

- The **chiral unitary method** sums up all diagrams of s-channel
- For **attractive interaction**, there would be **resonances**

K-P scattering

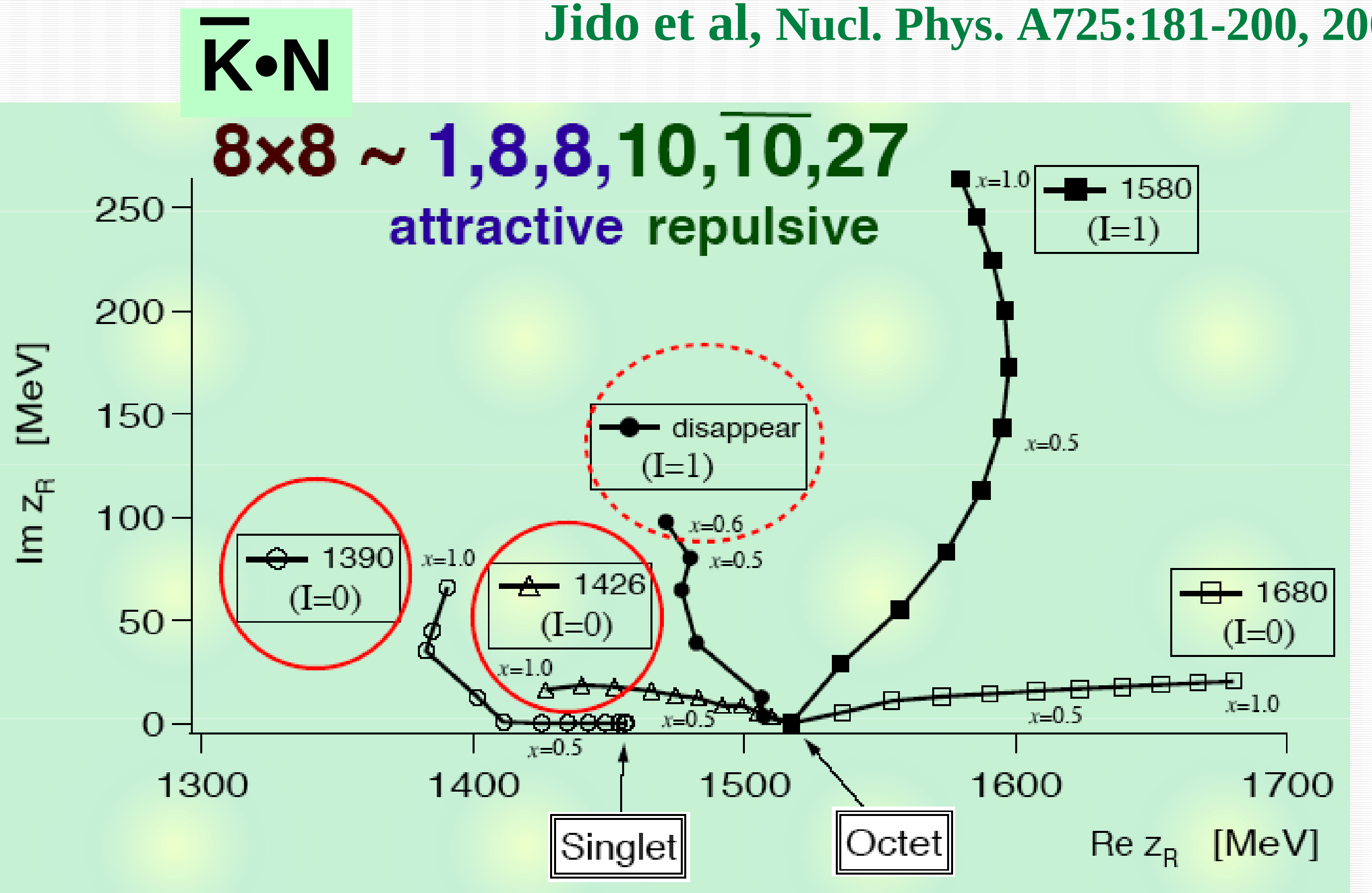
$K^- p \rightarrow mB$

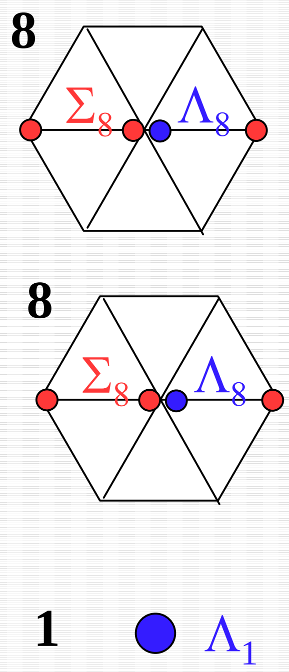
T. Hyodo, *et al.*, Phys. Rev. C 68, 018201 (2003)



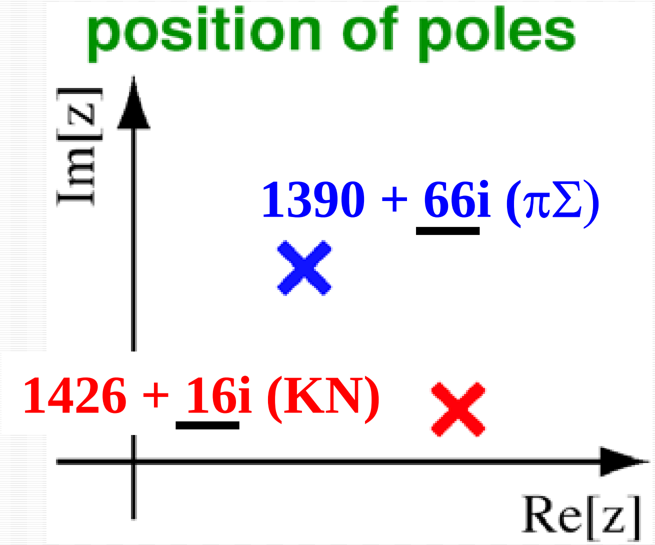
Two poles around Λ(1405)

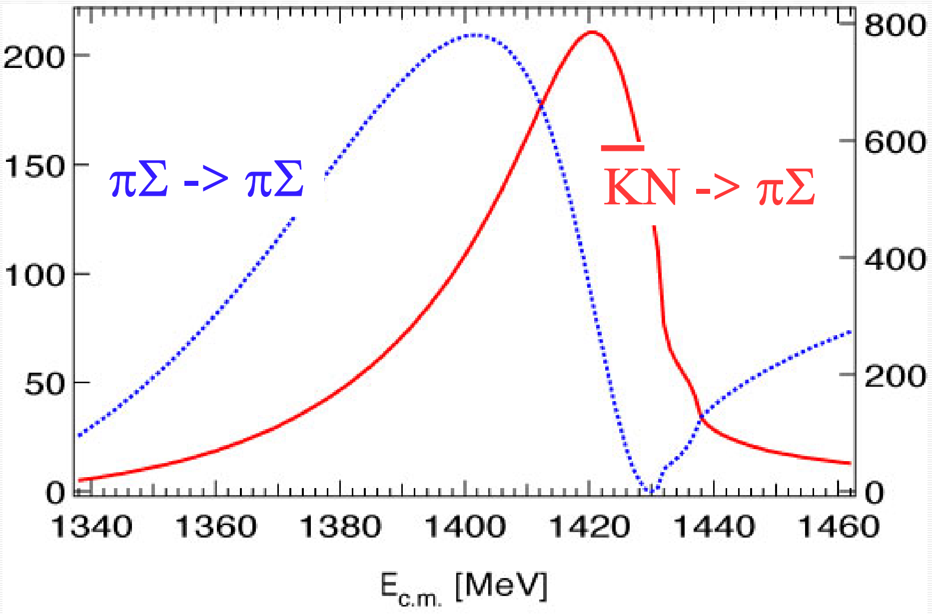
Jido et al, Nucl. Phys. A725:181-200, 2003





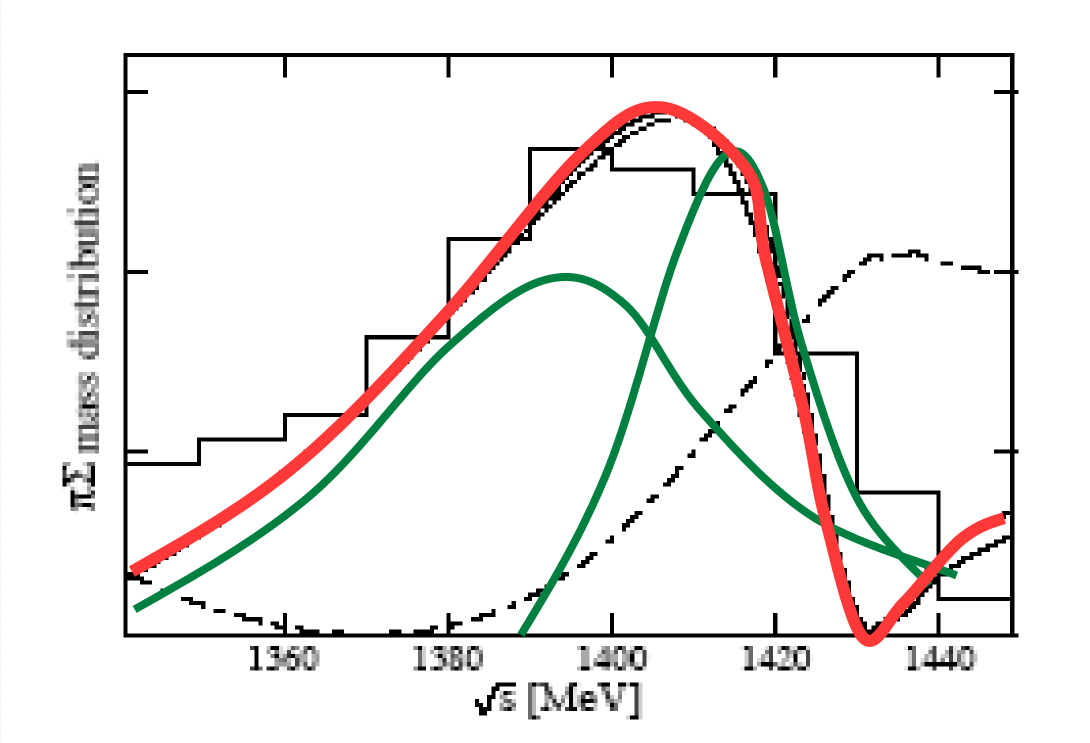
Location and shape





Observe different shapes of the two poles
Kaon-induced reactions

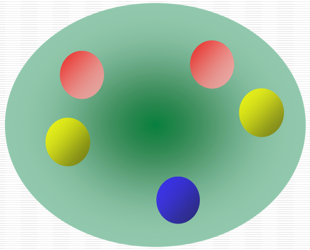
Mass distribution

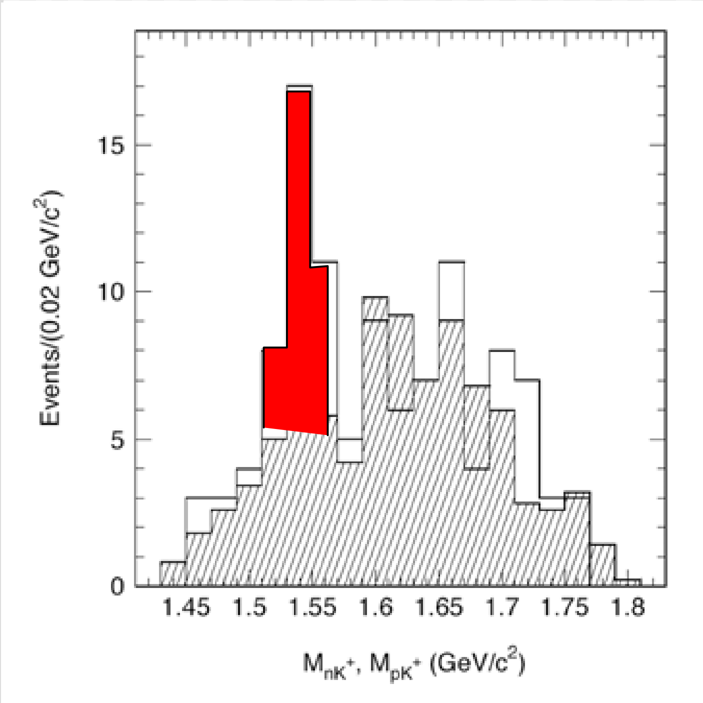


Summary for Λ(1405)

- Chiral models predict **two poles** for KN quasi-bound states
- The **higher one** couples to **KN**
  The **lower one** to $\pi\Sigma$
- Interesting to test chiral dynamics

Pentaquark Θ^+





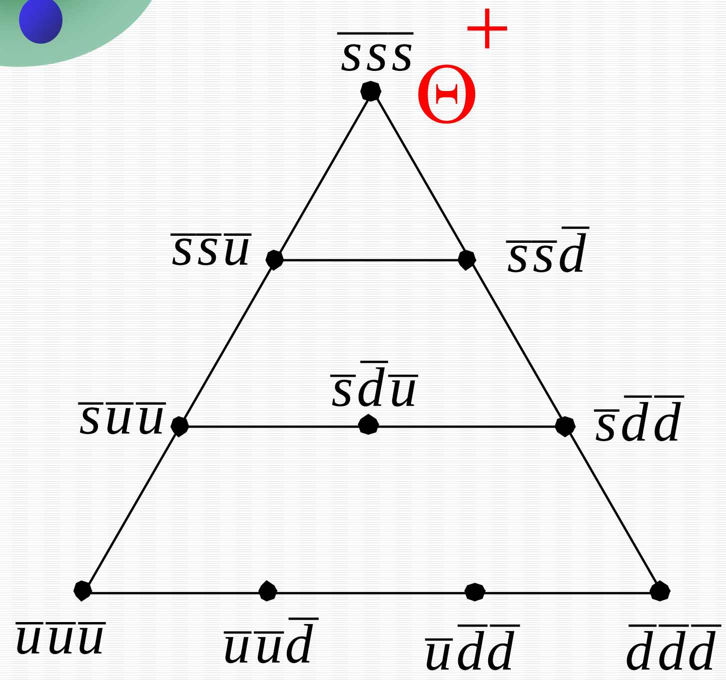
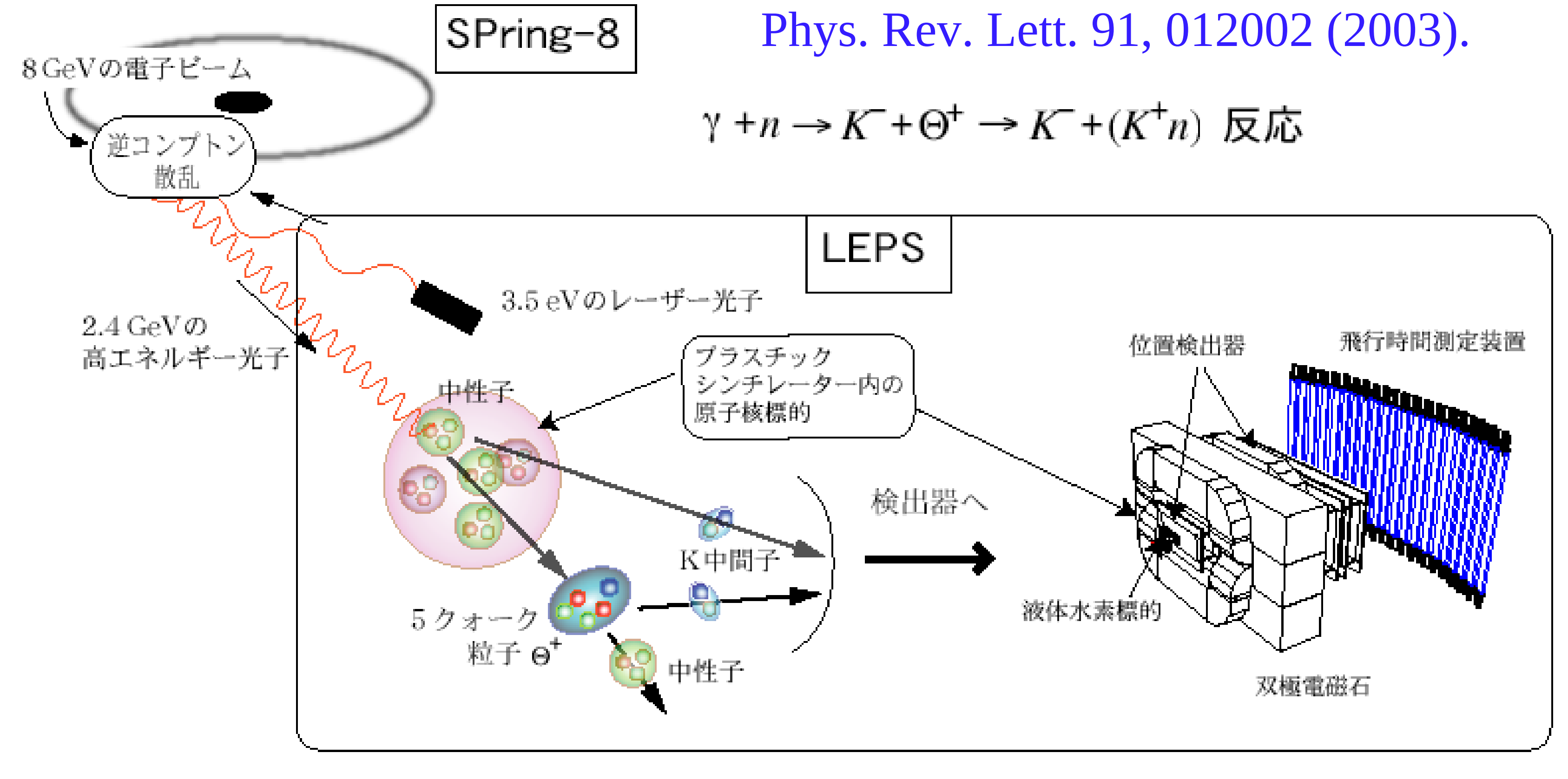


Photo-production at LEPS

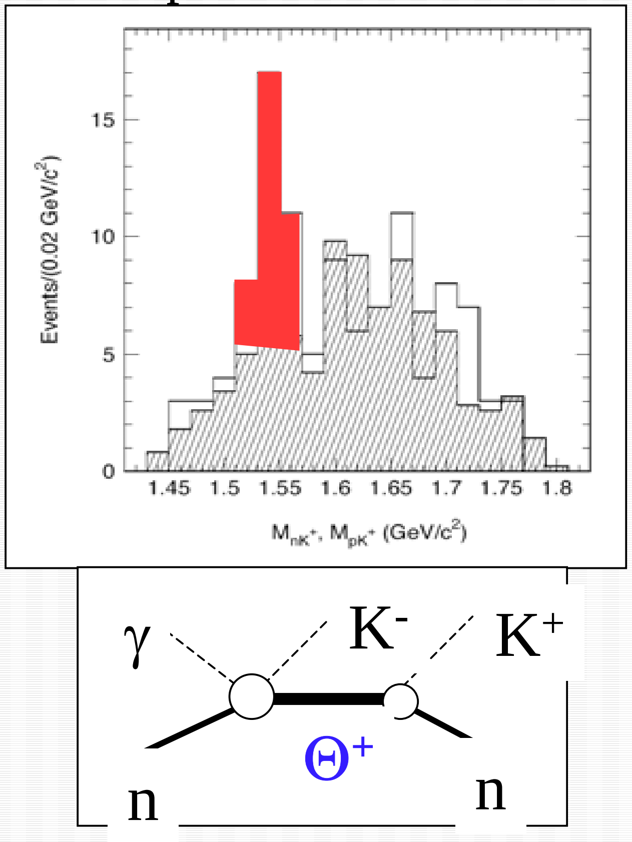
T. Nakano et. al. (LEPS collaboration), Phys. Rev. Lett. 91, 012002 (2003).

$$\gamma + n \rightarrow K^- + \Theta^+ \rightarrow K^- + (K^+ n)$$ 反応

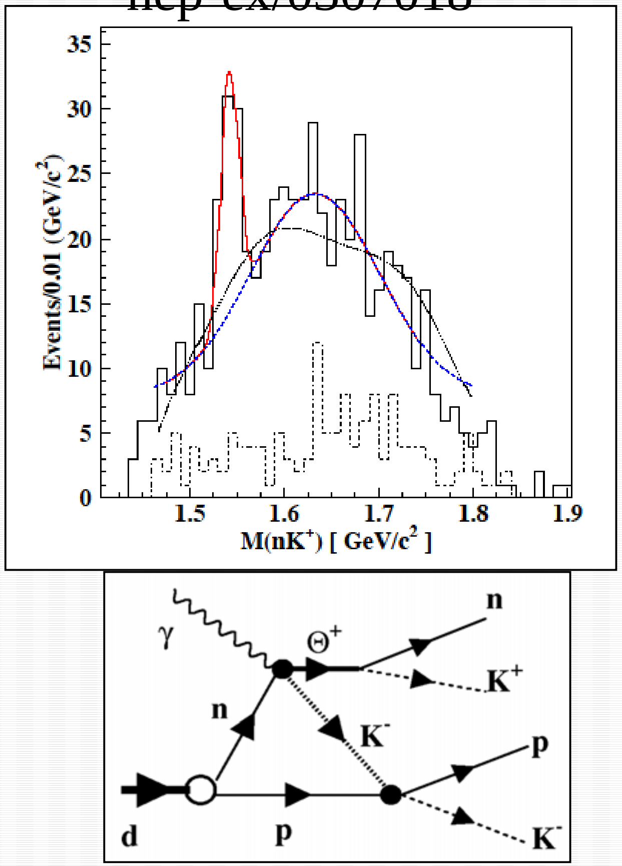


Some data

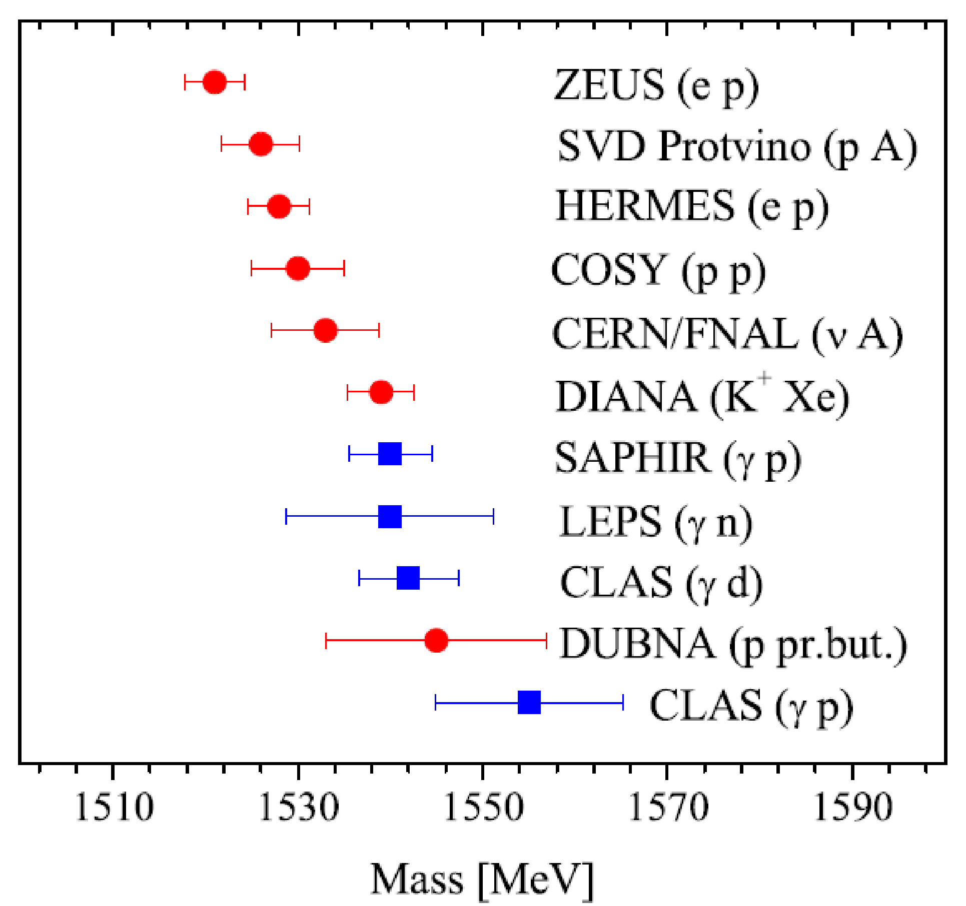
LEPS at Spring-8
hep-ex/0301020

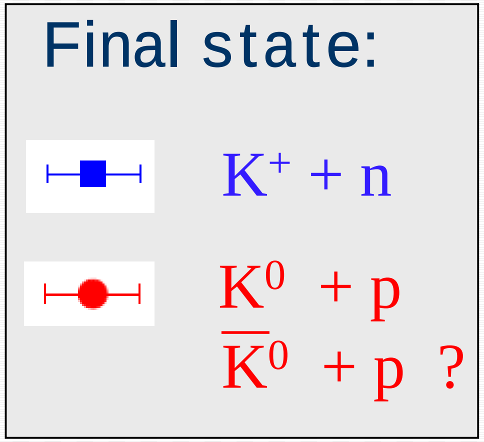


CLAS at J-Lab
hep-ex/0307018



Experiments





Negative results

- E690 (pp, $\sqrt{s}$ = 39 GeV)
- CDF($p\bar{p}$, $\sqrt{s}$ = 1.96 TeV)
- BaBar (e^+e^-, $\sqrt{s}$ = 10.58 GeV)
- Belle (e^+(3.5GeV)e^-(8GeV)
  => K^+(~1GeV)N)

Data

$$800\ GeV$$

$$pp \rightarrow (pK_s)K^- \pi^+ p$$

Cinsider reaction mechanism

Titov-Hosaka-Date-Ohashi
High energy preceses may be
Suppressed by quark counting

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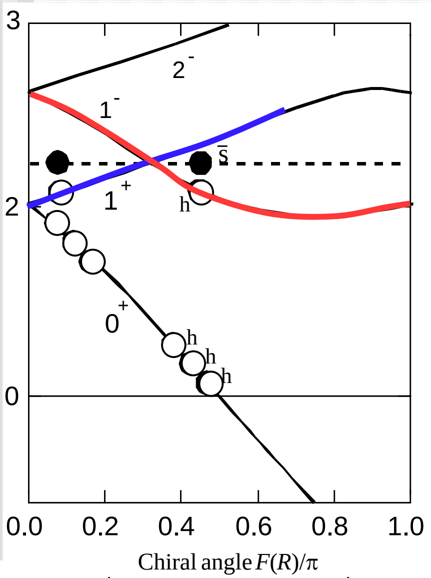
Theory

	Mass	Spin	Parity	Width
Quark model	~1.7 GeV ~1.9 GeV	1/2, 3/2	- +	Too large OK
Chiral soliton	~1.5 GeV	1/2	+	OK
Lattice	~1.5 GeV	1/2 (assumed)	- (+?)	?
Sum rule	~1.5 GeV	1/2 (assumed)	- (+?)	?

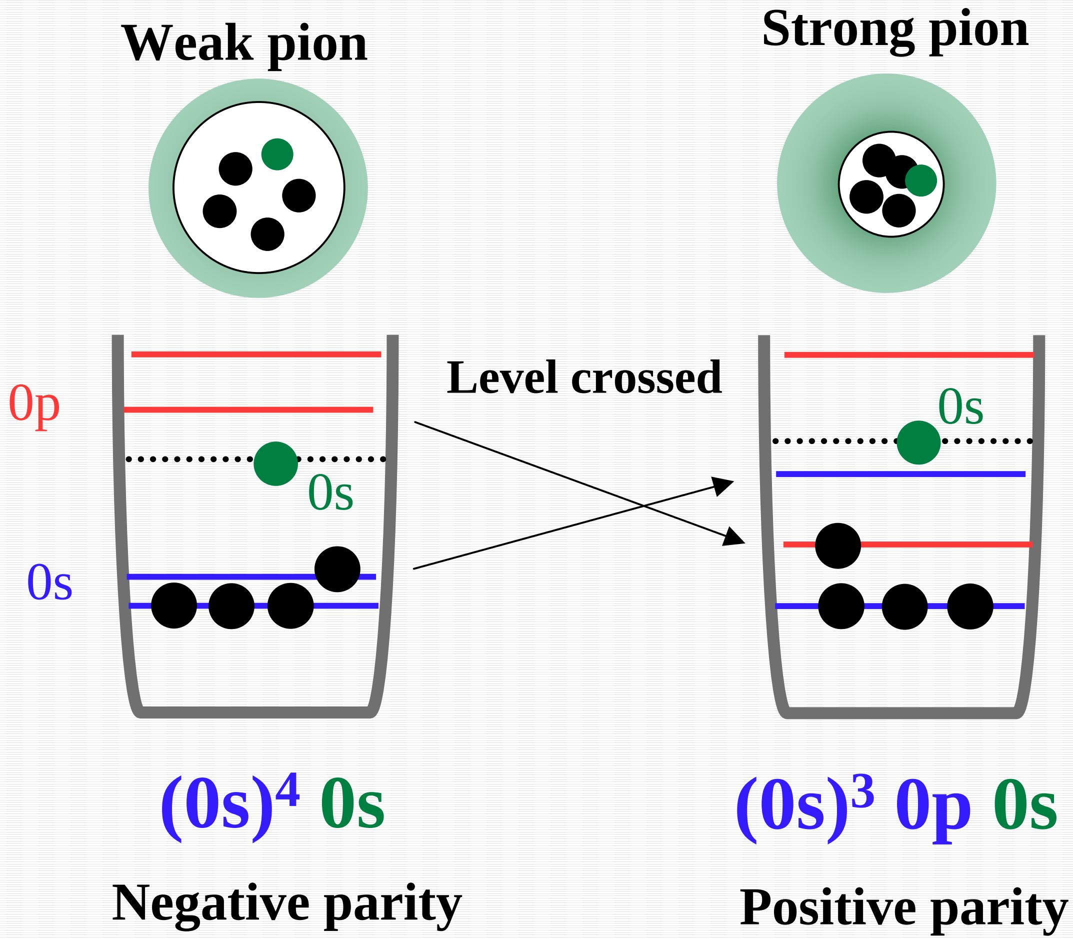
Chiral dynamics?

Parity

Chiral bag



bag ⟷ Skyrmion



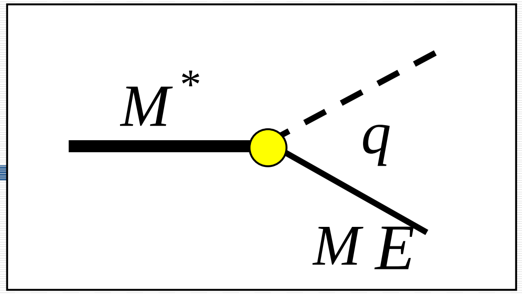
Decay width   Very sensive to parity

Quark model calculation

Positive vs. Negative parities

Exact calculation of 5-body system

Decay of baryons



1/2+ P-wave coupling

$$L = g_{KN\Theta} \bar{N} \gamma_5 \Theta K \quad \rightarrow \quad \Gamma^{+} = \frac{g_{KN\Theta}{}^2}{2\pi} \frac{Mq^3}{E(E+M)M^*}$$

For M^* = 1540 MeV, g = 13, then **Γ= 180 MeV**

If g = 4, then **Γ= 20 MeV**

1/2- S-wave coupling

$$L = g_{KN\Theta} \bar{N} \Theta K \quad \rightarrow \quad \Gamma^{-} = \Gamma^{+} \frac{(E+M)^2}{q^2}$$

~ 50 !

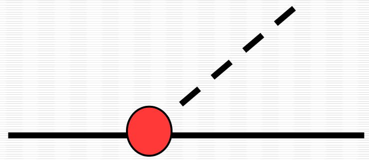
Γ= 9 GeV

1 GeV

Rough estimate in the quark model

πqq

$$L_{\pi qq} = g\bar{q}\gamma_5 \pi q \rightarrow \quad g\frac{\sigma_q q}{2m_q}$$



Through the GT relation

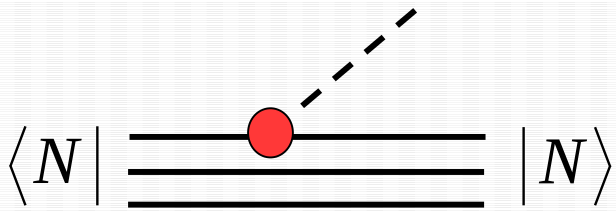
Matrix element of axial current

πNN

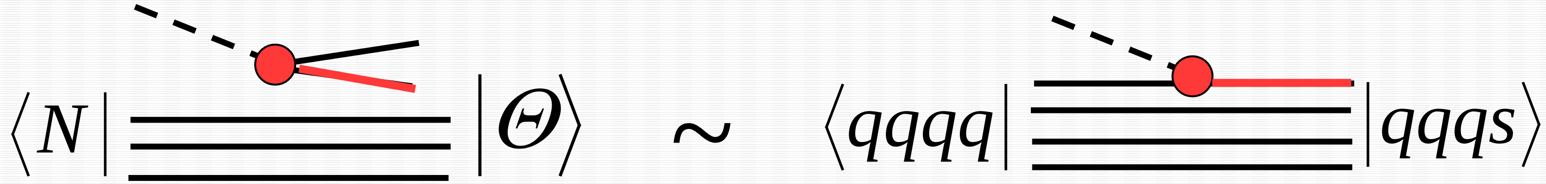
$$g_{\pi NN} \sim (N_c + 2)g \sim 5g$$

~ 13

Coherent sum over Three quarks



KNΘ



Without sum over quarks

$g_{KN\Theta} \sim 4$

$\Gamma \sim$ 20 MeV, if P = +

$\sim$ 1000 MeV P = -

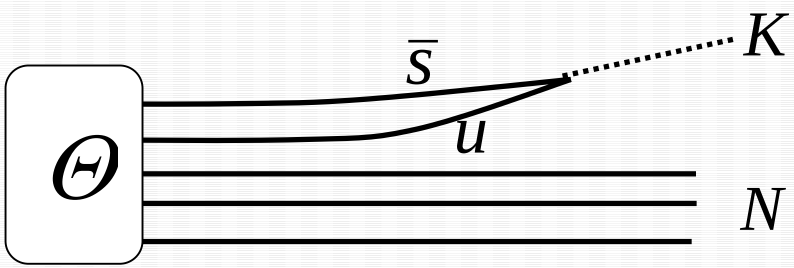
Natural width

Actual calculation

Negative parity

Assume SU(6) and **$(l=0)^5$** ~ ground state

SFC wave function is **uniquely** determined



$$|\Theta\rangle = \frac{1}{2}|KN\rangle + \ldots$$

$$= \frac{1}{2\sqrt{3}}|K^* N\rangle + \ldots$$

$g \sim 3$
$\Gamma \sim 500$ MeV

1/2- state is almost continuum

Positive parity

More complicated than s-wave due to p-wave excitation

1. **Attractive for sf interaction** $\sum_{ij} \vec{\sigma}_i \cdot \vec{\sigma}_j \; \lambda_i^a \lambda_j^a$

$$|\Theta\rangle = \sqrt{\frac{5}{96}}|KN\rangle + \ldots$$

g~8 => Γ~ 80 MeV

$$\frac{g_{K^*N\Theta}}{g_{KN\Theta}} = \sqrt{3}$$

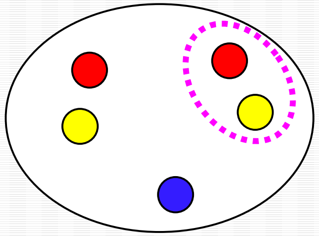
2. **Attractive for cs interaction**

$$|\Theta\rangle = \sqrt{\frac{5}{192}}|KN\rangle + \ldots$$

g~6 => Γ~ 40 MeV

3. Diquark correlation

Jaffe-Wilczek
hep-ph/0307341
Phys.Rev.Lett. 91 (2003) 232003



qq $S = 0, I = 0, C = 3^*$

Correlation in CSF part only (no orbital)

g~3 => Γ ~ 10 MeV

Decay width of positive parity can be small
negative parity is likely to be large
(strongly coupls to scattering states)

4. Dynamical calculation of 5-body system

Hiyama, talk at Pentaquark04

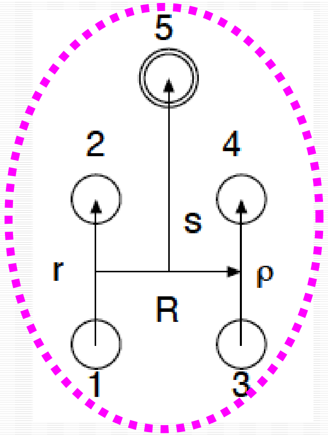
With Kamimura, Hosaka, Toki and Yahiro

Very recent and new accurate calculation for five body system

$$H = \sum \left(m_i + \frac{p_i^2}{m_i} \right) + V_{conf} + V_{ss-corr}$$

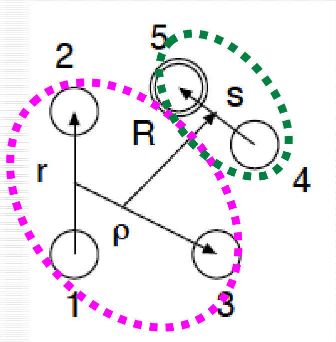
Gaussian Expansion Method
(Hiyama et al.)

$$|\Theta \sim qqqq\bar{s}\rangle =$$



Confined state

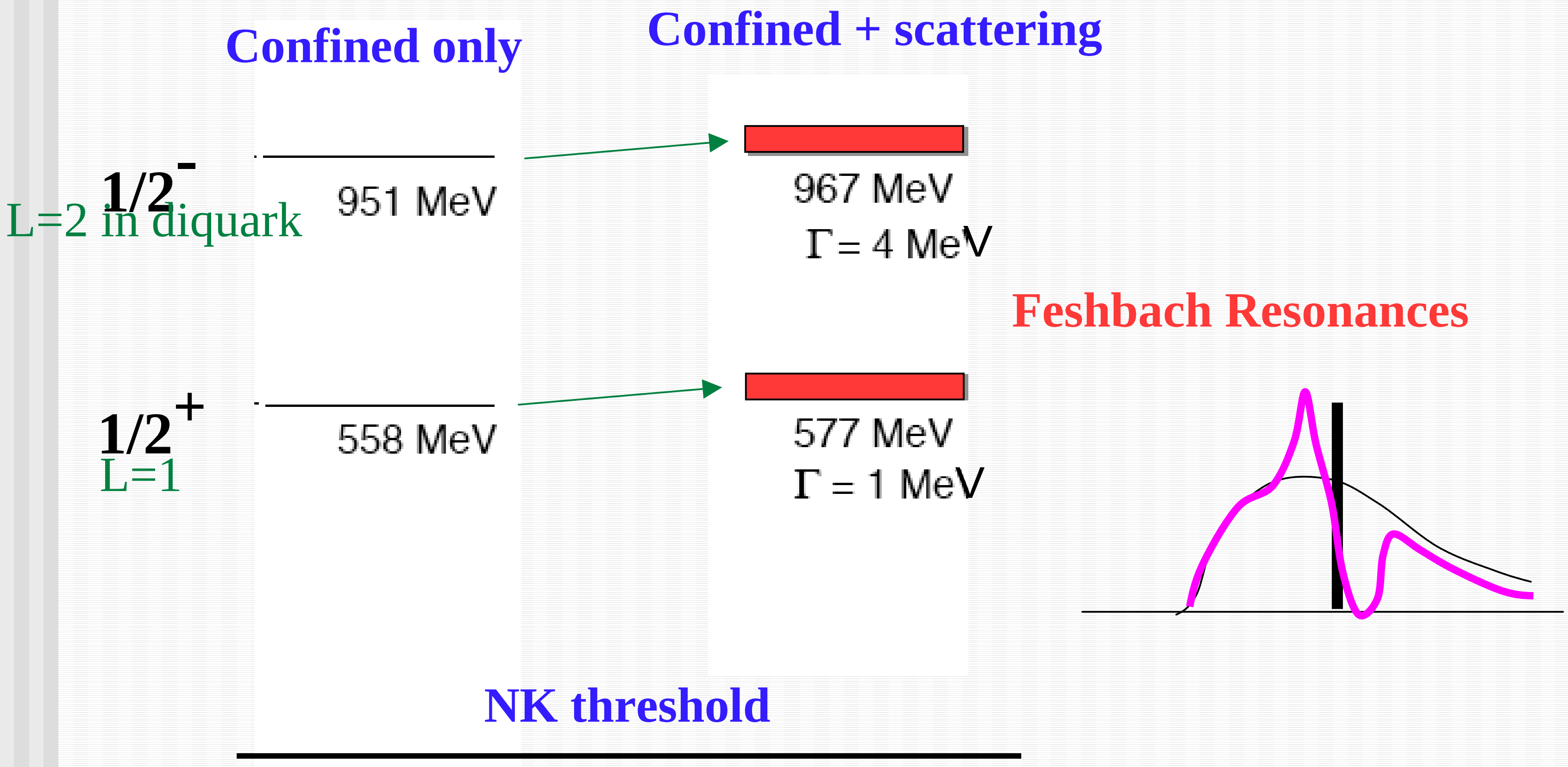
+



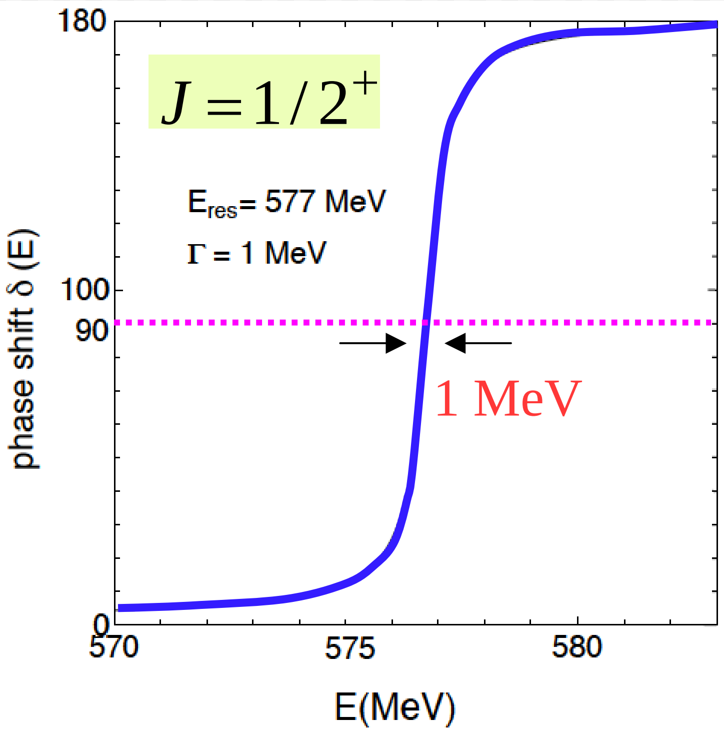
Scattering state

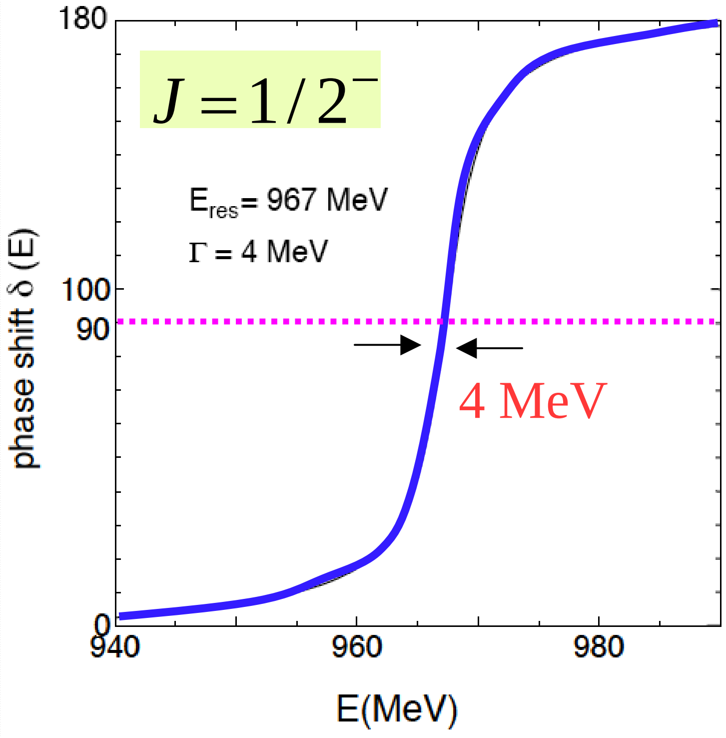
+ . . .

Energy levels

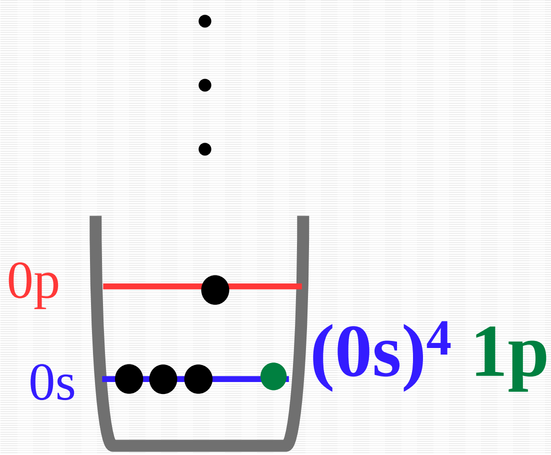


Phase shifts



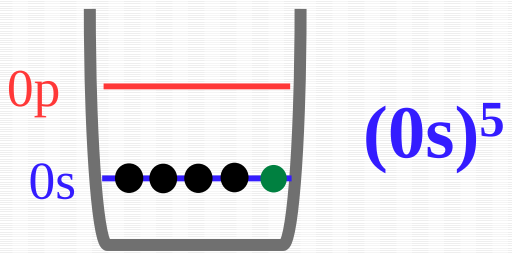


What we expect

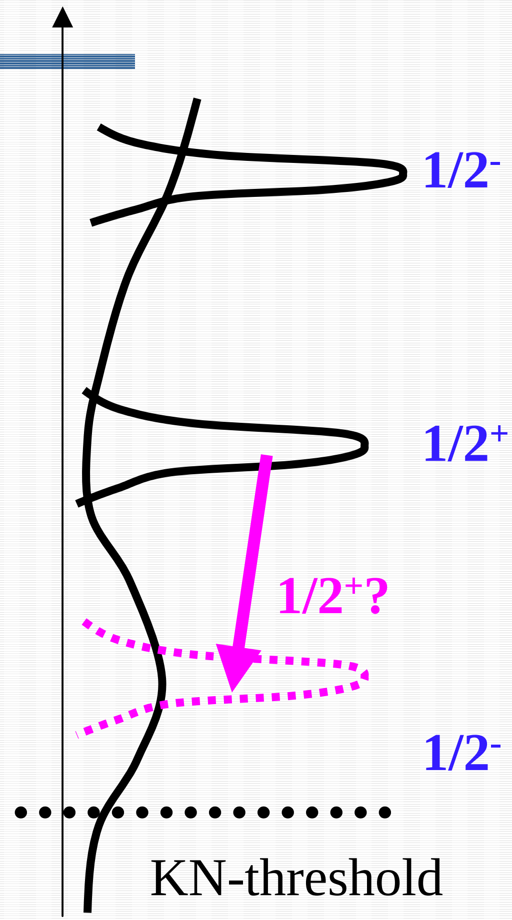


⋮

Positive parity
Energy high?
Narrow width



Negative parity
BUT almost continuum



Summary for Pentaquark

- Experimental and theoretical situations are not yet fixed

  Both chiral soliton and quark model prefer 1/2+
  Narrow decay width may be explained

  Need more theoretical study (Models, lattice,…)

- Narrow resonance (Γ ~1 MeV) indicates systems which can not be accessed by ordinary hadrons (processes).

- Reaction mechanism is crucially important.

Determining parity

(1) $\gamma + n \rightarrow K^- + \Theta^+$

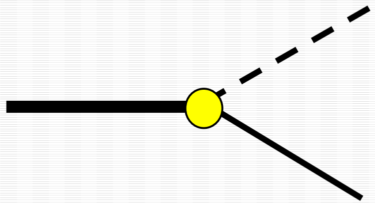
Nam-Hosaka-Kim
hep-ph/0308313, Phys.Lett.B579:43, 2004

(2) K* production

(3) K^+ induced reaqction

Hyodo-Hosaka-Oset
nucl-th/0307105, Phys.Lett.B579:290, 2004

Difficulty



1

$\vec{\sigma} \cdot \vec{q}$

When averaged over spin
=> Both are isotropic

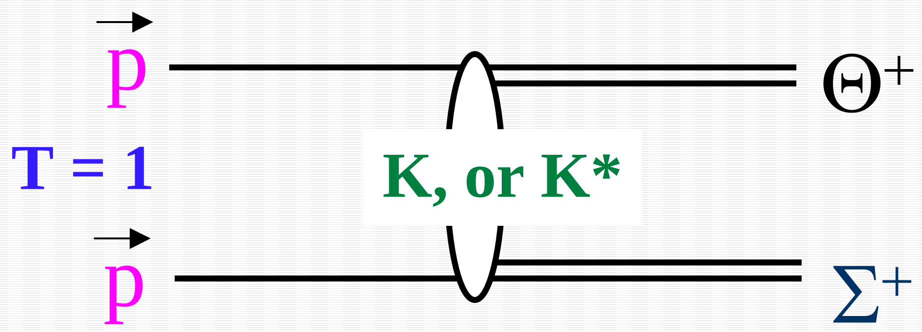
(4) Model-independent method

$$\vec{p}\vec{p} \rightarrow \Theta\Sigma$$

Thomas-Hicks-Hosaka
hep-ph/0312083, Prog.Theor.Phys.111:291,2004,

Nam-Kim-Hosaka, hep-ph/0401074

Model-independent method



At threshold
S-wave dominant

If S = 0, then L_i = even, P = even ==> **P(Θ) = +**

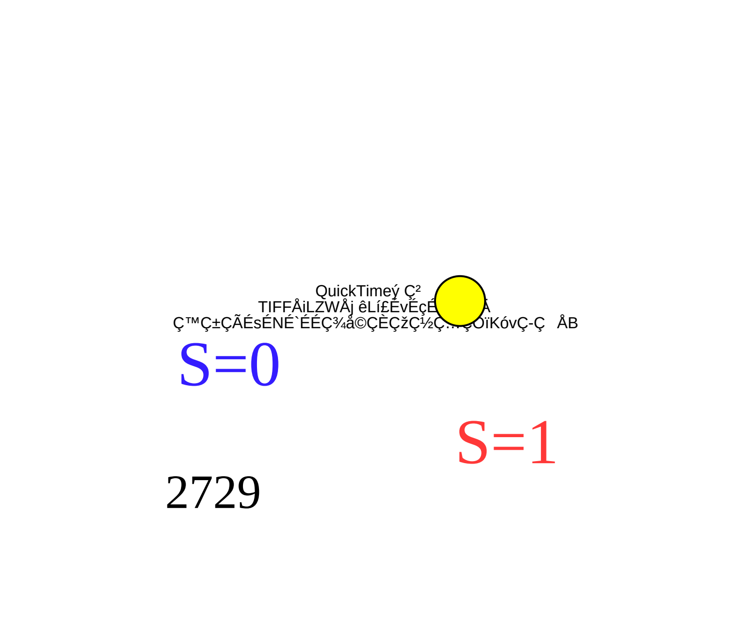
If S = 1, then L_i = odd, P = odd ==> **P(Θ) = -**

Cross sections

Nam-Hosaka-Kim,
hep-ph/0401074

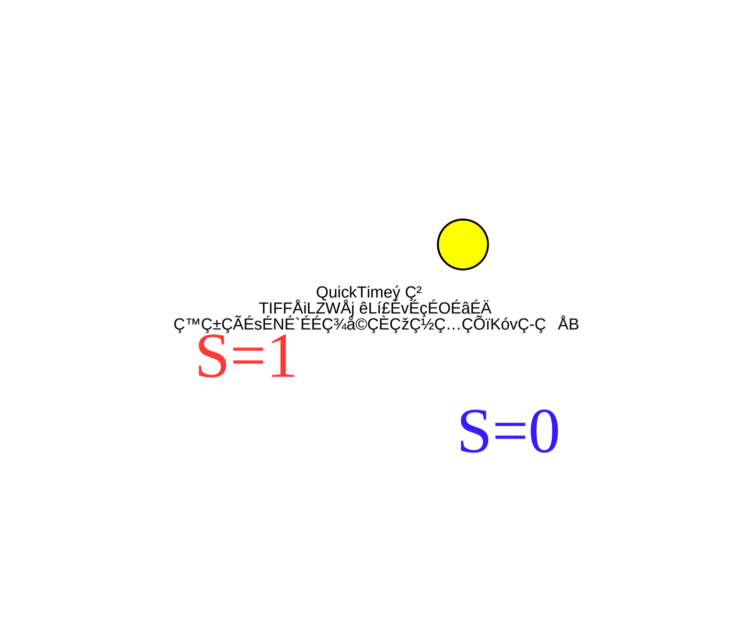
Γ = 15 MeV

Positive parity



1.5 μb

Negative parity



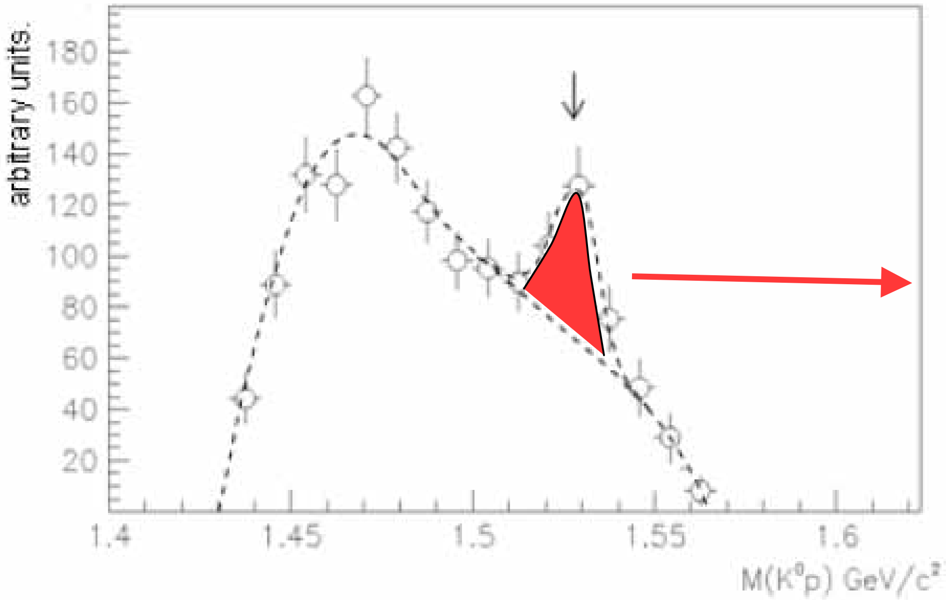
0.15 μb

Results from Julich

hep-ex/0403011

Beam mometum	excess energy	σ_{tot} (pp→pK$^0\Sigma^+$)
2.85 GeV/c	93 MeV	7.8 ±1.6 μb
2.95 GeV/c	126 MeV	12.7±1.3 μb
3.2 GeV/c	206 MeV	27.2±2.5 μb

32 MeV above ΘΣ



$$\sigma = 0.4 \pm 0.1 \pm 0.1\, \mu b$$

Γ = 18 +- 4 MeV

What we can say

At 30 MeV above the $\Theta\Sigma$ threshold
Reduction due to initial state int.

	Γ = 15 MeV
Positive parity	0.5 μb
Negative parity	0.05 μb

Factor 10 difference

Summary

Many baryons are fit into a nice systematics

Negative parity baryons are influenced by chiral meson-baryon int. Quasi MB states

There is much to study for Pentaquarks, not well explored by theory.
Interesting features from qqq, qqqqq, and more, before going to the multi-quark matter.